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THE USE OF ELECTRIC ANALOGUE COMPUTERS FOR THE INVESTIGATION OF THE COLD ROLLING PROCESS

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SUMMARY

The paper describes an electric digital computer developed by the Institute for Scientific Research in Computing Machinery for the investigation of aspects of the cold rolling process.

Introduction

Modern multi-stand cold rolling mills are very intricate aggregates both from the point of view of automatic control and of technology. Each of the stands of a cold mill is a self-contained mechanism where reduction of the strip-thickness is performed. The stand is provided with two systems for automatic control—one for the control of the main drive (rolling speed) and the other for controlling the screw-down mechanism (the roll-gap). At the same time all the stands are coupled by the strip being handled so that any change in the operating conditions in one of the stands provokes changes in all the other stands. Thus if for some cause or other there is a change in one of the stands (e.g. a decrease in the delivered gauge) a corresponding change will occur in the adjacent stand. As a result the torque of the main drive of the following stand will be reduced, whilst its speed will increase and this in turn will influence the behaviour of the next stand, and so on. Thus the multi-stand rolling mill should be considered as an inter-related system and in the study of the behaviour of such a system, not only should the technological characteristics and features of the individual stands (the rolling process) be taken into consideration, but also the power unit (the main-drive system and the screw-downs with their control devices).

Many problems arise in the design of new rolling mills and their solution is liable to influence greatly the exploitation features and technical characteristics of the future plant.

Bearing in mind the intricate design of the aggregates, the solution of the problems involved, even with the aid of calculating machines, presents great—and even insurmountable—difficulties. This is because the amount of computing is so large that several months of computer operation would be required for the calculation of only a few alternative solutions. It is quite clear that such a method is not feasible in designing new rolling mills. At the same time the increase in rolling speed necessitates immediate and careful investigation into the design of the rolling mill as this will ensure the correct design of the mill at a high technical level and also an adequate design of the drive and the automatic control.

With a view to this, the Department of Electric Analogue Computers at the Institute for Scientific Research in Com-

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puting Machinery developed, in 1956, a special electric analogue computer for studying the process of cold-rolling in multi-stand mills.

Choice of Analogue Computer

The development of an analogue computer rather than a digital computer for this purpose may be explained by the following considerations:

(a) The electric analogue computer is a considerably simpler and cheaper machine than the digital computer.

(b) In investigations carried out on rolling mills with the aid of computing machines it is desirable to be able to connect the computer with sections of the operating plant, e.g. the regulator (control unit) with the stand simulator (model). This would be difficult with a digital computer because the transfer equipment is rather intricate and the operation of a digital computer on a real time scale presents a great many difficulties.

(c) The accuracy of the results obtained in the course of investigations carried out with electric analogue computers is precise enough to satisfy engineering requirements.

(d) The electric analogue computer does not require special programming and allows the influence of various parameters to be determined in a simple form readily understandable by the technologist.

Description of Computer

For economy, the electric analogue computer only completely simulates three stands as where the rolling mill comprises more that three stands the simulating of the other stands, if required, may be effected in succession, beginning for example, with the first three stands and then proceeding with the simulation of the third, fourth, and fifth stands, and so on.

The electric analogue computer for the type MH-12 rolling mill comprises three unitype sections, each section simulating a single mill stand with its related equipment. Each section consists of:

(1) Ten integrating d.c. amplifiers.
(2) Twenty summing d.c. amplifiers.
(3) Twelve d.c. inverting amplifiers (for changing the sign of input data).

4. Four special units reproducing the relationship for the inertia member

$$\frac{U_{output}(P)}{U_{input}(P)} = K_{(p)} = \frac{K}{1 + pT}.$$

5. Two units reproducing the relationship for the forcing member, of the following form:

$$\frac{U_{output}(P)}{U_{input}(P)} = K_{(p)} = \frac{1 + pT_1}{1 + pT_2}.$$

6. Two multiplying units.

7. Two units for the execution of the relationship $U_{input} f(t)$. (Variable coefficients units.)

8. One unit for reproducing the function with delayed argument of the form $U_{output} = U_{input} (t - \tau)$; where τ is a function of another variable, for example of the angular speed (expressed as tension).

9. Two universal nonlinear units for reproducing the following relationship:

$$U_{output} = U_{output_0} + dU_{input} +$$
$$\sum_{i=1}^{n} (\beta_i U_{input\ i} - U_{input\ i\ initial})$$
$$i = 1, 2, 3, \ldots 10.$$

Moreover, in the section are included special nonlinearities, which are pertinent to the rolling mill automatic control system, viz.: two nonlinear dead zone and saturation units; two nonlinear backlash units; and two nonlinear units for reproducing the hyperbolic function and the saturation curve.

The electric analogue computer is provided with two special cathode-ray oscilloscopes for the observation of the modification of variables in the course of the investigations. By means of these instruments the behaviour of variables in solving the problems may be easily watched on the afterflow screen of the cathode-ray tube.

All non-linear units with the exception of the multiplying units are built with transitor or vacuum diodes and allow the approximation of preset non-linear functions by means of constant lengths (or steps). In the design of the multiplying units the non-linear relations (quadratics) of thyrites are used. Multiplication is effected by the equation:

$$4xy = (x + y)^2 - (x - y)^2$$

To reduce costs, common d.c. amplifiers having deep negative feedbacks and no stabilisation of zero drift are used.

The delay unit is designed on the electro-mechanical principle with "memory" condensators. The modification of the delay value (τ) is achieved by means of a servo-system.

Linear approximation is used to increase the accuracy of the operation of the unit. This enables a function with a delayed argument to be obtained which is approximated by a total of 20 linear lengths rather than by constant steps.

The electric analogue computer may be used to operate either in one section or in all the three sections simultaneously. The computer may be successfully used not only for the solution of problems related to the simulating of the rolling mill, but also for the investigation of other problems connected with the development of automatic control systems.

While designing the electric analogue computer for the rolling mills two kinds of difficulties were experienced. The first and main difficulty was in obtaining mathematical relations representing the processes taking place in the rolling mill stands, its drives, and the automatic control

systems. The second difficulty was encountered in developing special units (delay units, special nonlinear units and others), and in solving problems related to the design of an analogue computer circuit, capable of satisfying the requirements of rolling most efficiently.

As a result of the research work carried out in the Central Research Institute of Engineering Technology equations were developed describing the drives of separate stands and control systems and also technological equations representing the process of metal reduction.

A motor generator unit comprising two motor amplifiers (MA), one of which being a compensated amplifier (the voltage applied to this amplifier is proportional to the current of the main motor) and the other, a differential amplifier (the voltage applied to this amplifier is equal to the error voltage, i.e., the difference between the compensated amplifier voltage and the preset voltage, was adopted as the main drive. The latter controls the generator exciting voltage. Transformers with flexible feedbacks are provided in the circuits of both amplifiers.

The main drive system in conjunction with the control system is simulated in the analogue computer by a set of fourteen differential nonlinear equations, including equations of finite relations.

The operation of the stand proper (i.e. the technological relations) are represented in the analogue computer by a set of six non-linear equations. To simplify the system and to increase the accuracy of the analogue computer, the technological equations are not formed for the values proper but for their deviations. The description of the set of equations for the screwdowns which may also be simulated in the analogue computer are given in Reference 1.

A preliminary simulation in a separate circuit was made for the set of equations representing the main drives and the technological processes taking place in the stand and the interstand connections. Investigations carried out with this circuit showed that the adopted set of equations gives a reasonable representation of the processes occurring in the rolling mill.

Special units which are not available in currently manufactured analogue computers were also developed during these researches.

Use of the Computer

Investigations were subsequently carried out to determine the main parameters of the system which exercise considerable influence on the behaviour of the rolling mill. As a result of solving some particular problems it was shown that the equations for the rolling mill main drive may be approximately replaced by the delay term plus the inertia term of the first order.

In particular, such a substitution allows the determination of the main features and structure of the computing device which is a component of the control system and is designed to ensure a better control of the gauge of the strip.

The investigations carried out with the electric analogue computor have demonstrated that by using this device it is possible to reduce the deviation of strip gauge previously encountered by several times.

Moreover, operational means for starting and stopping the mill—which were considered as most typical from the point of view of transient operational conditions—were also studied by means of the analogue computer. At the present time the computer is being used for carrying out further investigations in the field of rolling processes.

References

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